An **AVL Tree** is a self-balancing **Binary Search Tree (BST)** where the height difference (balance factor) between the left and right subtrees of any node is **at most 1**.

Balance Factor (BF)

BF=Height of Left Subtree−Height of Right Subtree

- **BF = 0, 1, or -1 → *Balanced***
- **BF > 1 or BF < -1 → *Unbalanced***

Steps for Insertion in an AVL Tree

1. **Insert the new node like in a normal BST**
2. **Update heights of affected nodes**
3. **Check balance factors from the inserted node up to the root**
4. **Perform rotations if necessary**

Types of Rotations for Balancing

Case 1: Left-Left (LL) – Right Rotation

Occurs when a node is **left-heavy** (**BF > 1**) and the inserted node is in the **left subtree**.
Fix: Perform a **Right Rotation (Single Rotation)**

Example: Insert 10 into this tree

```
   30
   /
  20
 /
10
```

Right Rotate (at 30) →

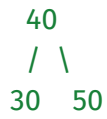
```
   20
   /  \
 10    30
```

Case 2: Right-Right (RR) – Left Rotation

Occurs when a node is **right-heavy** (**BF < -1**) and the inserted node is in the **right subtree**.
Fix: Perform a **Left Rotation (Single Rotation)**

Example: Insert 50 into this tree

Left Rotate (at 30) →



Case 3: Left-Right (LR) – Left Rotation + Right Rotation

Occurs when a node is **left-heavy** (**BF > 1**) but the inserted node is in the **right subtree** of the left child.
Fix:

1. Perform **Left Rotation** at the left child
2. Perform **Right Rotation** at the unbalanced node

Example: Insert 25 into this tree

Step 1: Left Rotate at 20 →

Step 2: Right Rotate at 30 →

```
  25
  /  \
20   30
```

Case 4: Right-Left (RL) – Right Rotation + Left Rotation

Occurs when a node is **right-heavy** (**BF < -1**) but the inserted node is in the **left subtree** of the right child.

Fix:

1. Perform **Right Rotation** at the right child
2. Perform **Left Rotation** at the unbalanced node

Example: Insert 45 into this tree

```
30
  \
   50
  /
 45
```

Step 1: Right Rotate at 50 →

```
30
  \
   45
     \
      50
```

Step 2: Left Rotate at 30 →

```
  45
  /  \
30   50
```

Example

Let's insert **[50, 30, 70, 20, 40, 60, 80]** step by step:

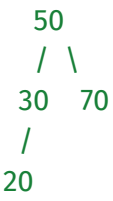
Insert **50** → Root

```
50
```

Insert **30** → Left of 50

Insert **70** → Right of 50

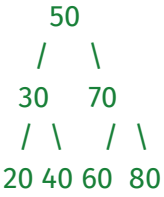
Insert **20** → Left of 30



Insert **40** → Right of 30

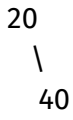
Insert **60** → Left of 70

Insert **80** → Right of 70 (Balanced)

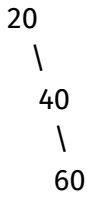


Another example:
[(20:O), (40:S), (60:T), (80:R), (89:N), (70:E), (30:T), (10:N), (33:A), (31:H), (24:R), (32:E)]

Insert 20
20

Insert 40


BF(20)= 1 - 0 = 0 (Balanced)

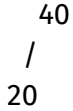
Insert 60


BF(40) = 0 - 1 = 0
BF(20) = 0 - 2 = -2

- Imbalance at node 20

RR Rotation

- Rotate at node 20



BF(40) = 1 - 1 = 0 (Balanced)
BF(60) = 0 - 0 = 0 (Balanced)
BF(20) = 0 - 0 = -2 (Balanced)

Insert 80
Insert 89
Insert 70
Insert 30
Insert 10
Insert 33
Insert 31
Insert 24
Insert 32